Celebrating

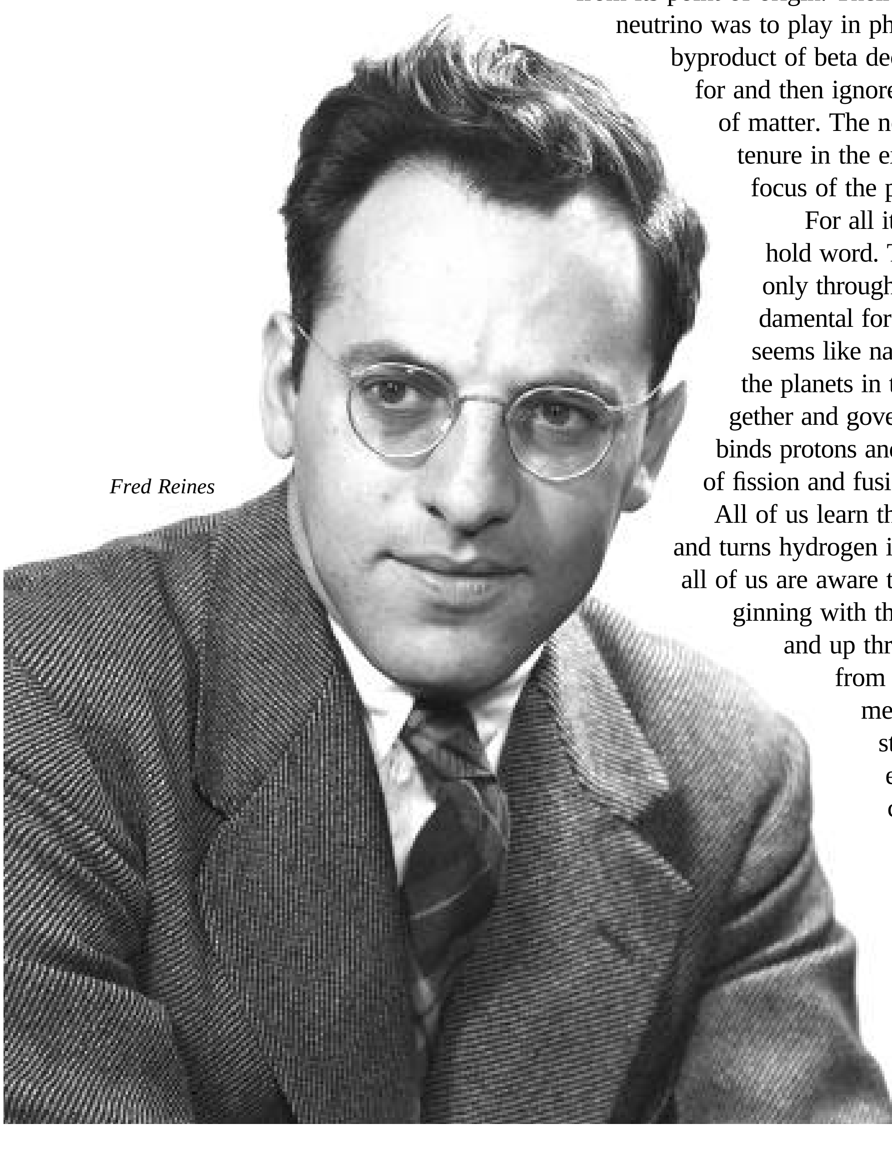
Receiving the Nobel Prize for the detection of the neutrino is a great honor not only for Fred Reines personally but also for Los Alamos National Laboratory—this is the first time Laboratory-sponsored work has received such recognition. The Laboratory is extremely proud of Reines for bringing that honor to it.

In 1995, Fred Reines was awarded the Nobel Prize in physics for the detection of the neutrino, perhaps the most intriguing and certainly the most elusive of nature's elementary particles. Wolfgang Pauli had "invented" the neutrino in December 1930, when the only known particles were the proton, the electron, and the photon, and the contents of the nucleus were still a mystery. The new particle was to carry away the missing energy in beta decay, the nuclear decay process in which a nucleus of one element expels an electron and changes to the nucleus of the next higher element in the periodic table. The invisible particle accompanying the electron had to have the same spin as the electron, but little or no mass, and it had to be electrically neutral. Most importantly, it had to interact with matter very very weakly to explain why it was never observed in the experiments of the day.

Pauli viewed this hypothesis as a desperate attempt at saving the time-honored law of energy conservation. But a few years later, Enrico Fermi used the concept of the neutrino to develop his very successful theory of beta decay. By association, the neutrino became real in the minds of most physicists even though this particle was believed to be impossible to detect. Then, in the 1950s, Reines, Clyde Cowan, Jr., and their Los Alamos team finally showed that the neutrino could be observed away from its point of origin. Their ground-breaking experiments changed the role that the neutrino was to play in physics. It would no longer be merely the invisible byproduct of beta decay, a passive partner to the electron to be accounted for and then ignored, but a useful tool for uncovering the basic structure of matter. The neutrino's fascinating "career" in physics and long tenure in the experimental programs at Los Alamos provides the focus of the present volume.

For all its staying power in physics, the neutrino is not a household word. The reason is simple: The neutrino interacts with matter only through the weak force, the least known of nature's four fundamental forces. Compared with the other three, the weak force seems like nature's afterthought. Gravity holds us to Earth and keeps the planets in their orbits. The electromagnetic force holds atoms together and governs the chemistry of the elements. And the strong force binds protons and neutrons into nuclei and governs the nuclear processes of fission and fusion. But what role does the weak force play?

All of us learn that fusion produces the energy that powers the stars and turns hydrogen into helium and helium into heavier elements. But not all of us are aware that the weak force is at work in these processes. Beginning with the fusion of one proton with another to make deuterium and up through the periodic table—from hydrogen to helium, from helium to carbon, and so on—the making of the elements includes not only the merging of nuclei through the strong force but also the slower transmutation of one element into another through the weak force. In each case, the weak force causes a neutron to transform into a proton or a proton into a neutron. Simultaneously, it keeps electric charge constant by creating or destroying an electron (or its antiparticle, the positron). And it keeps something called weak charge constant by creating or destroying the neutrino (or the antineutrino), the electron's weak partner.



Fred Reines

the Neutrino

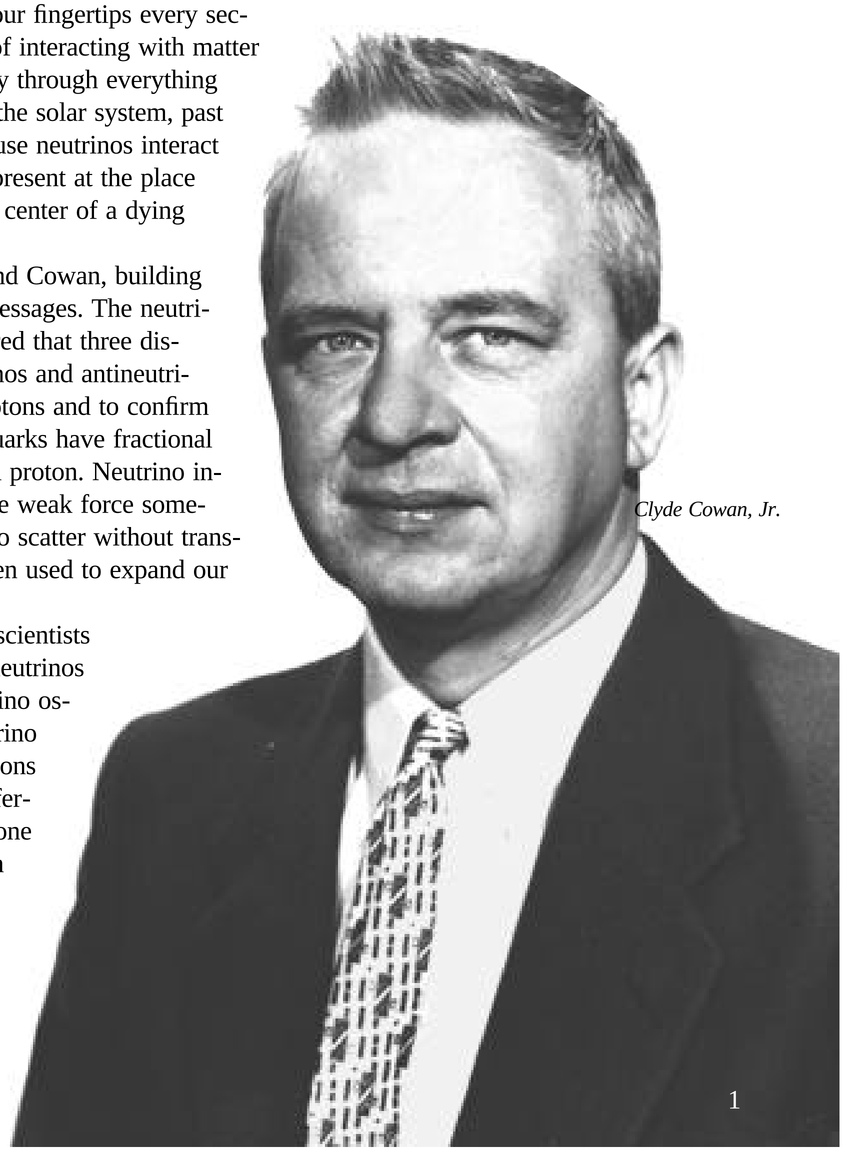
The weak force began to shape the universe during the first hundred seconds following the Big Bang. Neutrons and protons were in thermal equilibrium, and they interacted through the weak force (as well as the strong) to create the primordial abundances of helium and other light elements. Today the weak force continues to shape our world, causing the Sun to shine for us by day and the stars to twinkle in the heavens by night. Whether in the interior of stars or in the expanding envelopes of supernovae, the weak force is at work making all the elements we know on Earth. It is the force of transmutation. Without it, the elements, and therefore we, would never have come to be.

And so, the neutrino's importance becomes apparent: Wherever the weak force plays a role, we usually find the neutrino either as a relic of the interaction or as a major participant. We are permeated by a thermal background of neutrinos, which, like the background of cosmic microwave radiation, is a leftover from the Big Bang. These neutrinos decoupled from the rest of matter about one second after the Big Bang and continued to expand and cool on their own. There are about three hundred of them in every cubic centimeter of our universe. Because of Earth's proximity to the Sun, we are also drenched by a giant flux of neutrinos from the fusion reactions in the Sun's core: roughly 600 billion solar neutrinos go through our fingertips every second. But these elusive neutrinos have such a small chance of interacting with matter that their presence goes mostly unnoticed. They pass silently through everything they meet as they begin an almost endless journey through the solar system, past our galaxy, and out to the far reaches of the universe. Because neutrinos interact so little, however, they preserve a record of the conditions present at the place of their creation—whether at the center of the Sun or at the center of a dying star on its way to becoming a supernova.

Many physicists have followed in the footsteps of Reines and Cowan, building oversized detectors to trap the neutrinos and decode their messages. The neutrino's intrinsic properties were measured, and it was discovered that three distinct types, or flavors, of neutrino exist. High-energy neutrinos and antineutrinos were used to probe the substructure of neutrons and protons and to confirm (in conjunction with electron scattering experiments) that quarks have fractional charge and that triplets of quarks make up each neutron and proton. Neutrino interactions with matter were also used to demonstrate that the weak force sometimes acts like the electromagnetic force, causing particles to scatter without transmuting their identities. Time after time, the neutrino has been used to expand our understanding of the subatomic world.

Today, the neutrino is at center stage in particle physics as scientists approach a definitive answer to a most basic question: Do neutrinos have mass? The positive results from the Los Alamos neutrino oscillation experiment (called LSND for the name of the neutrino detector) suggest that the answer is "yes." Neutrino oscillations are a completely nonintuitive phenomenon in which the different neutrino flavors shift their identities and transform into one another. The shift is not caused by the weak force but by an interference phenomenon that can occur only if at least one neutrino flavor has mass. Thus LSND's positive results are of huge interest to physicists all over the globe. Confirmation of these results would finally prove that neutrinos have mass. It would also prove that neutrinos

Clyde Cowan, Jr., and Fred Reines led the team of talented scientists and technicians at Los Alamos that made the first definitive measurement of an event induced by a free neutrino, thus proving that this theoretical construct did indeed exist.



Clyde Cowan, Jr.

mix among their different flavors in the same way that quarks mix among their different flavors.

The added similarity between the quarks (strongly interacting particles) and the neutrinos (weakly interacting particles) would increase the hope that the world of elementary particles can be described by a Grand Unified Theory. This popular extension to the Standard Model of particle physics describes three of nature's forces as different aspects of a single force, and the neutrinos and all the elementary particles as different excitations of a single quantum field. The existence of neutrino oscillations would also suggest that this phenomenon is the explanation for the solar-neutrino puzzle, the measured shortfall in the flux of neutrinos coming from our Sun.

On a more local note, confirmation of the LSND results would mean that Los Alamos scientists have once again performed a historic experiment in the field of neutrino physics. Such an achievement would be a natural outcome of the ongoing commitment at Los Alamos to this particular field. Ever since the Reines and Cowan experiments, the Laboratory's scientists have exploited many resources to advance neutrino studies. The Los Alamos Neutron Science Center (formerly called LAMPF) became a tool to study the differences between muon and electron neutrinos. The Laboratory's expertise in isotopes and very low level radioactivity was applied to search for neutrinoless double beta decay, a process that would prove that the neutrino is a Majorana particle (a particle that is its own antiparticle). The Laboratory's nearly unique capacity for handling tritium was applied in a precedent-setting search to measure the mass of the electron neutrino directly. Later, Los Alamos scientists went beyond the Laboratory to join American and Russian colleagues in a solar-neutrino experiment known as SAGE, a successful effort to measure the low-energy solar-neutrino flux. Today they are helping to build a next-generation solar-neutrino detector at the Sudbury Neutrino Observatory in Canada. The LSND collaboration is now planning an experiment at Fermilab, hoping to pin down the size of neutrino masses. And finally theorists at Los Alamos are continuing to study the role of neutrinos as drivers of supernovae and the possible role of neutrinos as components of the dark matter that binds together the large-scale structures in the universe.

Thus, the type of research that Reines and Cowan took on in the 1950s is very much a part of the Los Alamos tradition, held to this day, of doing fundamental science side by side with mission-oriented work. Their project was also the first in a series of extraordinary efforts at Los Alamos to chase down and uncover the properties of the elusive neutrinos. To honor Reines, Cowan, and their colleagues and to celebrate their discovery and the work it inspired, this issue is devoted to the neutrino and its remaining mysteries.

In closing, let us note that the Nobel Prize for the detection of the neutrino is not only a great honor for Reines personally, but also for Los Alamos National Laboratory—this is the first time Laboratory-sponsored work received such recognition. The Laboratory is extremely proud of Reines for bringing that honor to it. Very sadly, Cowan was not alive to share the award with Reines, but his equal contribution is recognized by all, and in that knowledge, portraits of both men are now hanging beside some of the other great scientists who have graced this institution. ■

Neutrinos, they are very small.
They have no charge and have no mass
And do not interact at all.
The earth is just a silly ball
To them, through which they simply pass,
Like dustmaids down a drafty hall
Or photons through a sheet of glass.
They snub the most exquisite gas,
Ignore the most substantial wall,
Cold-shoulder steel and sounding brass,
Insult the stallion in his stall,
And, scorning barriers of class,
Infiltrate you and me! Like tall
And painless guillotines, they fall
Down through our heads into the grass.
At night, they enter at Nepal
And pierce the lover and his lass
From underneath the bed—you call
*It wonderful; I call it crass**